Negative tone imaging with EUV exposure for 1x nm node and beyond

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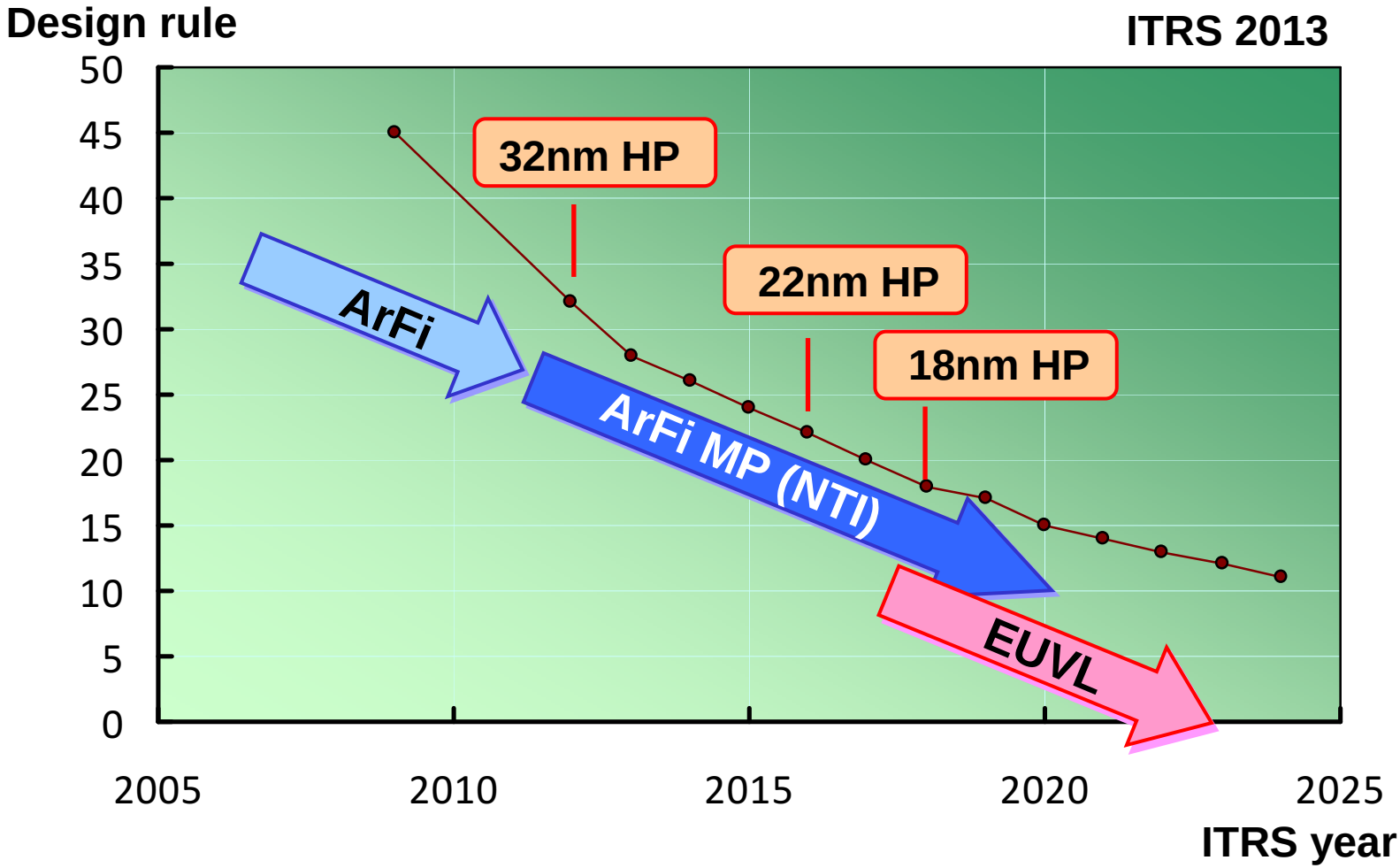
Outline

1. Motivation
2. Resist design beyond 16 nm HP
3. Benefits of negative-tone imaging (NTI)
4. Summary

Development status in FUJIFILM



EUVL is still main candidate for 1x nm HP (key challenge is to go beyond 16 nm HP)

Requirements for EUV resist

Performance

Resolution（<1x nm）

Collapse

Toploss

SPIE 2011, FUJIFILM

SPIE 2013, FUJIFILM

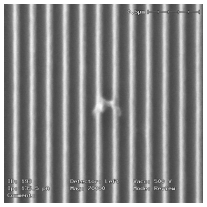
Sensitivity

（<20mJ）

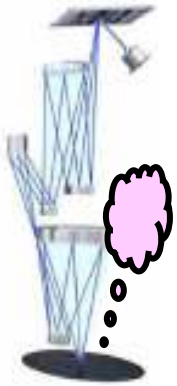
LWR (<3.0nm）

Quality

Defectivity



Outgas contamination

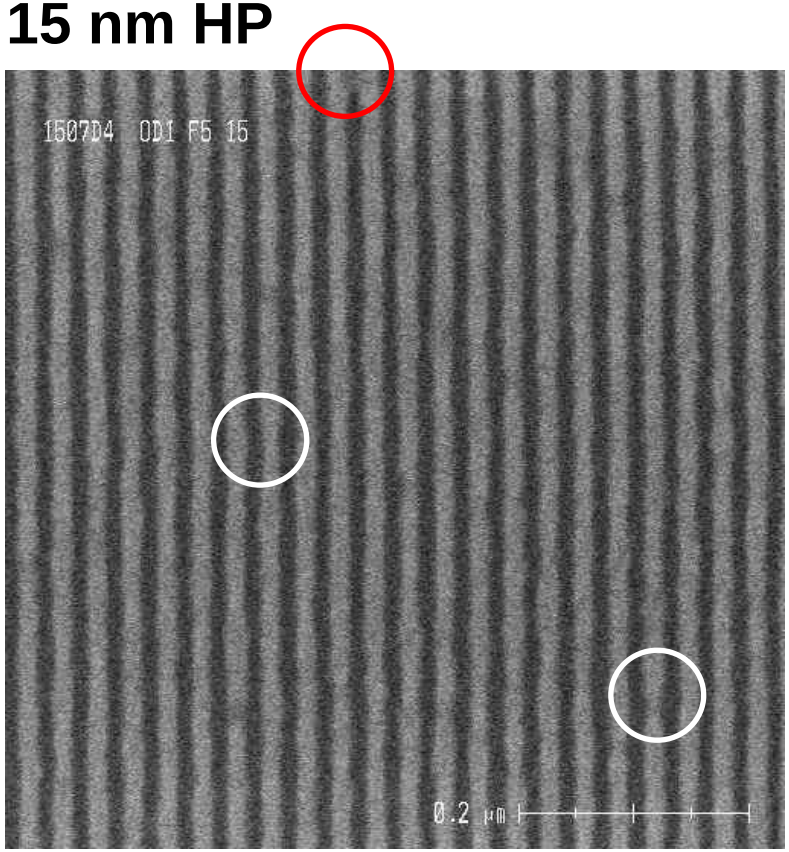


RLS is still most important challenge

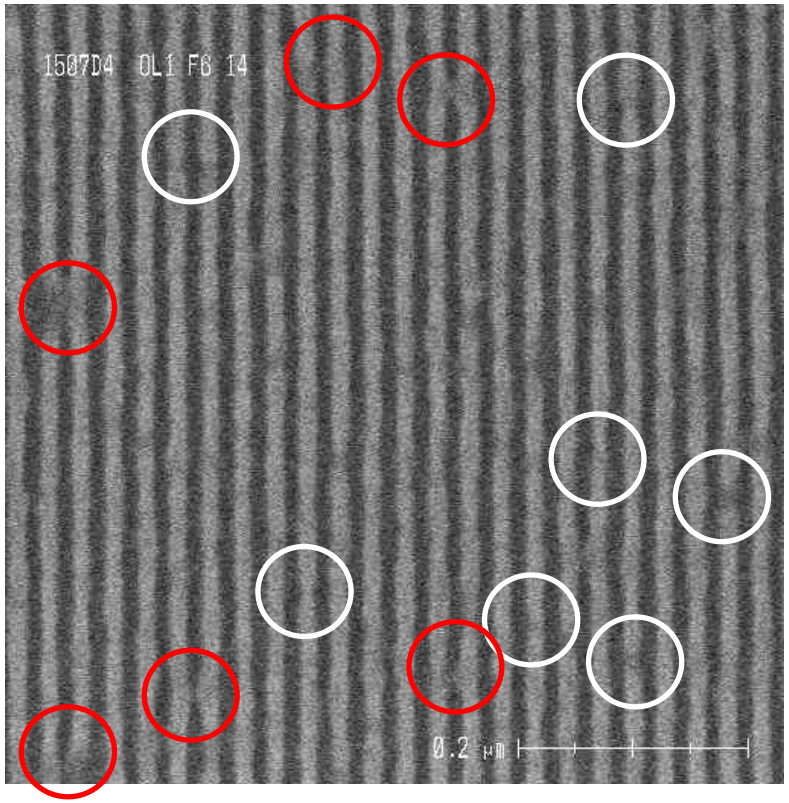
Key challenges on beyond 16 nm

-- PTI resist / process --

15 nm HP



14 nm HP



30.8 mJ/cm^2

Toploss (pinching), but bridge/collapse also restrict resolution

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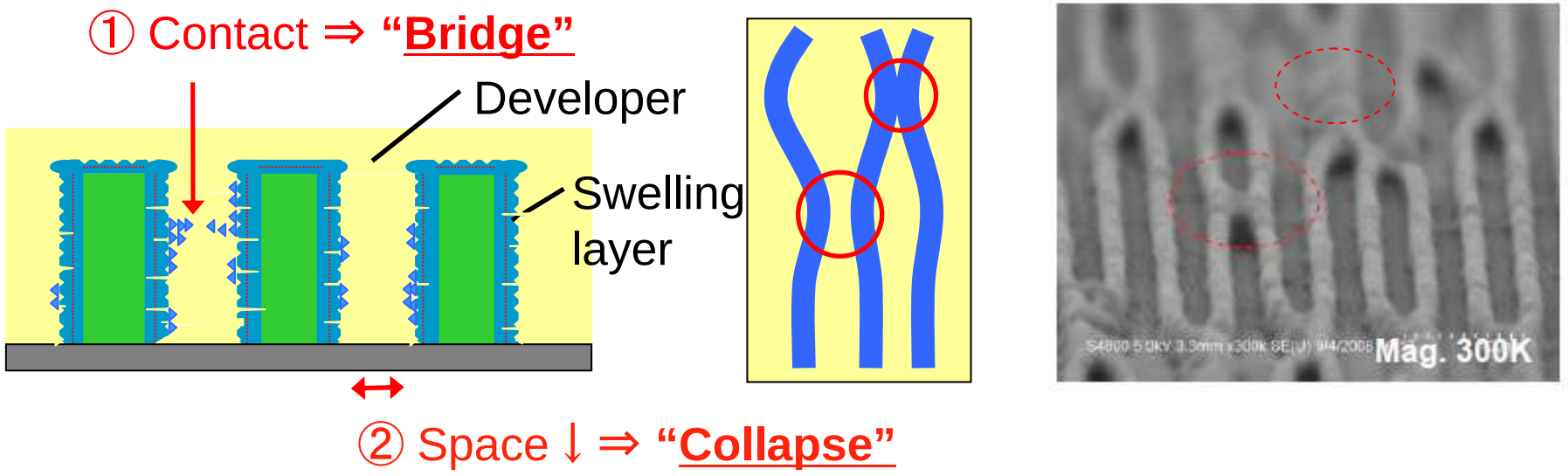
Swelling model

1) Development step

Developer penetration ⇒ Swelling of pattern ⇒ Tensile stress ⇒ deformation

2) Rinse, drying step

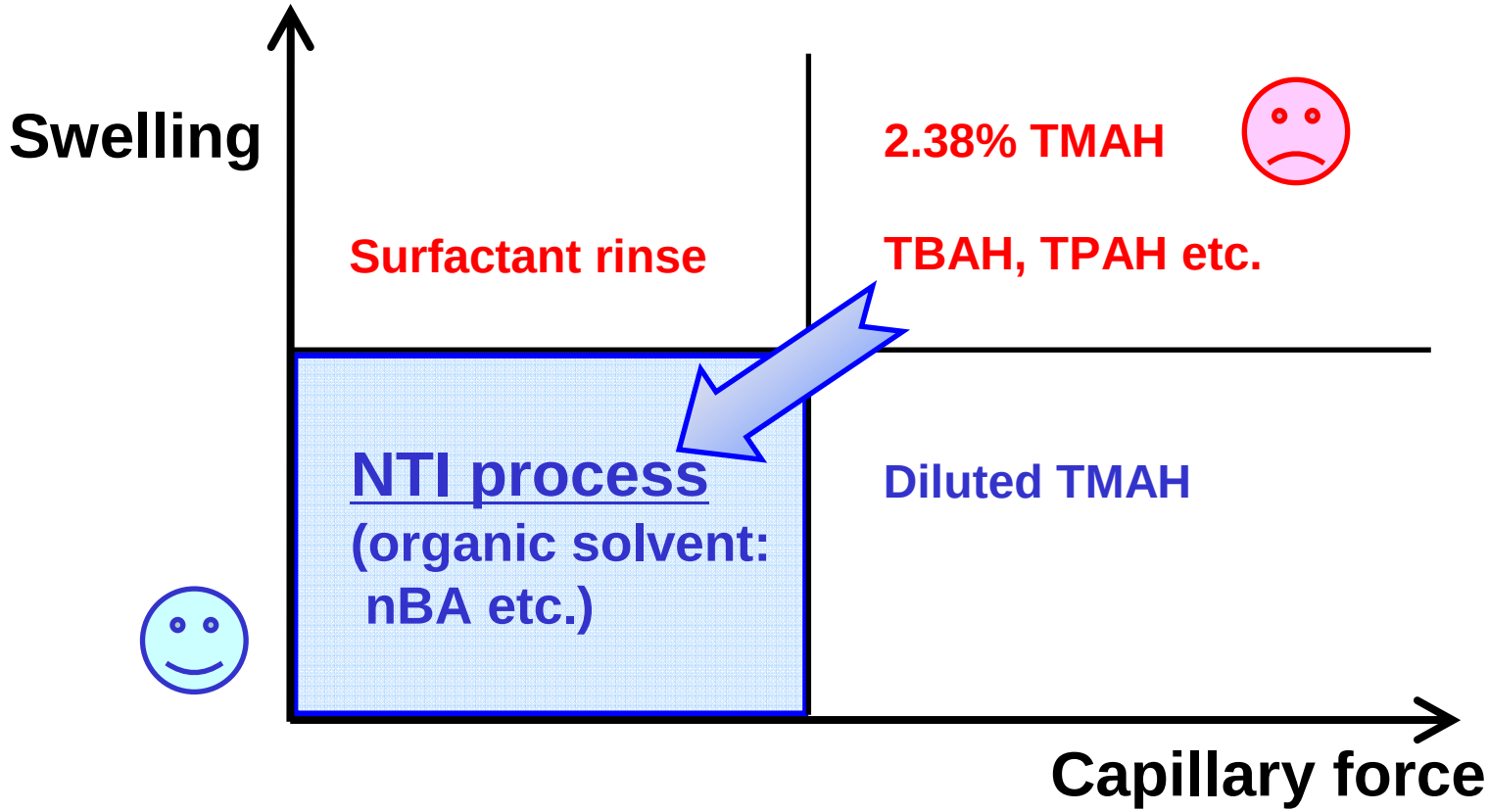
Actualize bridge and collapse



Swelling play a dominant role on bridge & collapse

How to address bridge/collapse

- Good bridge: non swelling
- Good collapse: non swelling, low capillary force

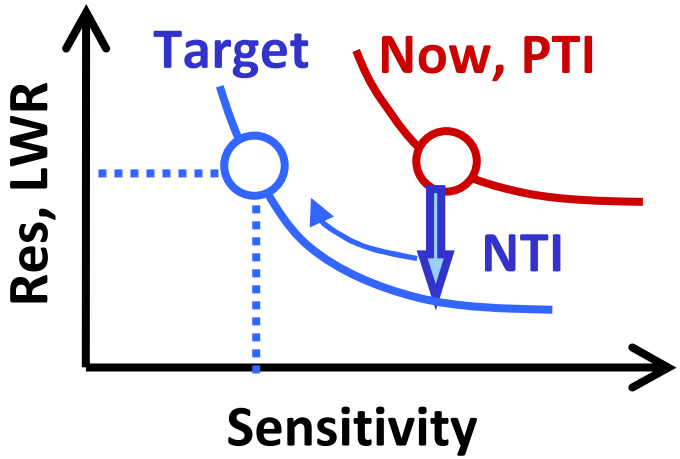


NTI must be a best solution

Overview of NTI benefits

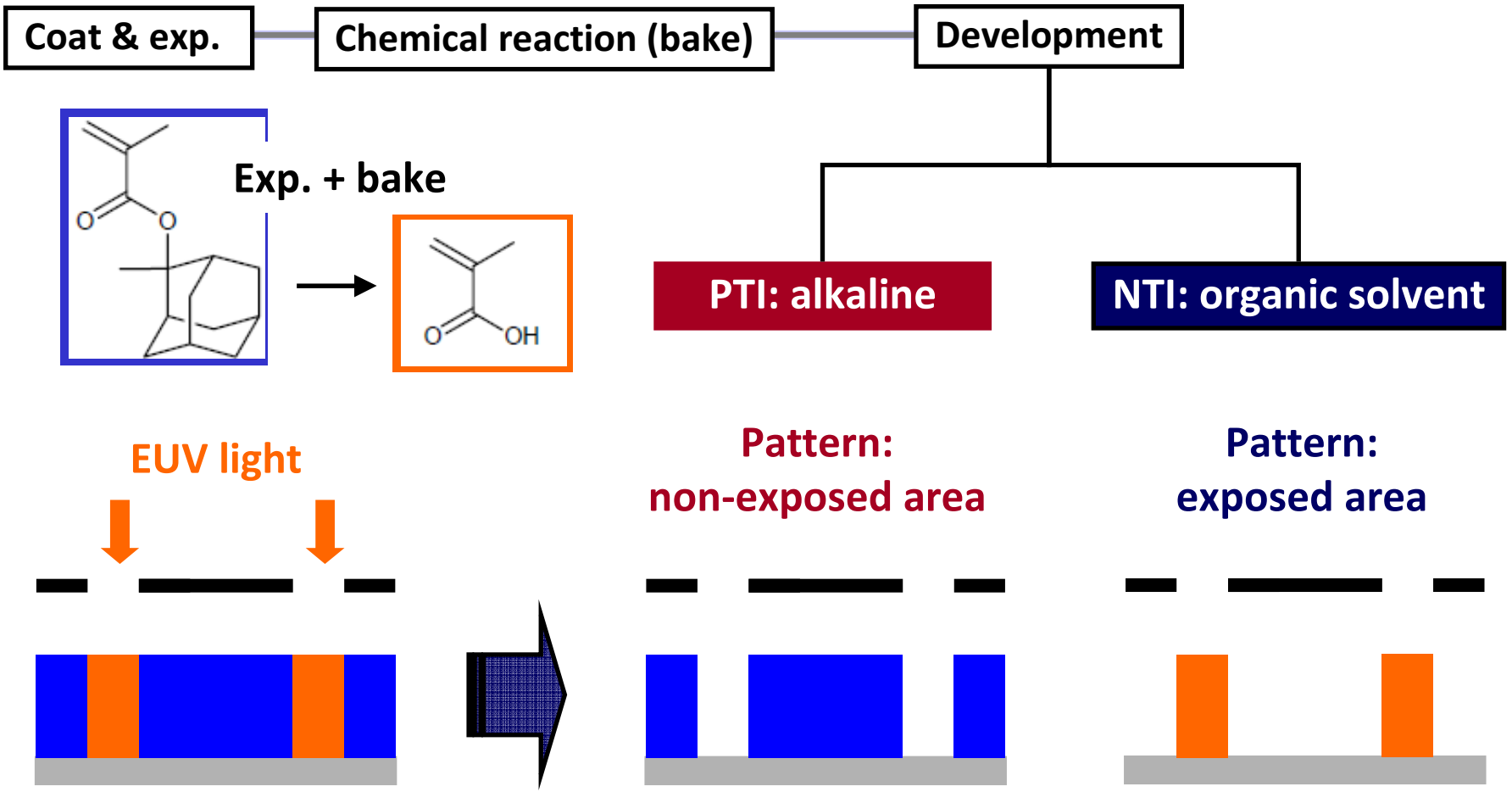
Characteristic of NTI (vs. PTI)	Performance advantage
1. Non-ionization ➔ Minimize swelling	Collapse, bridge
2. Organic solvent ➔ Low surface tension	Collapse
3. No aggregation ➔ Small grain size	LWR
4. No additive/pure solvent ➔ no defect	Defectivity

NTI has some advantages due to it's inherently good dissolution property



Drive organic development ➔ NTI system

What is NTI process ?



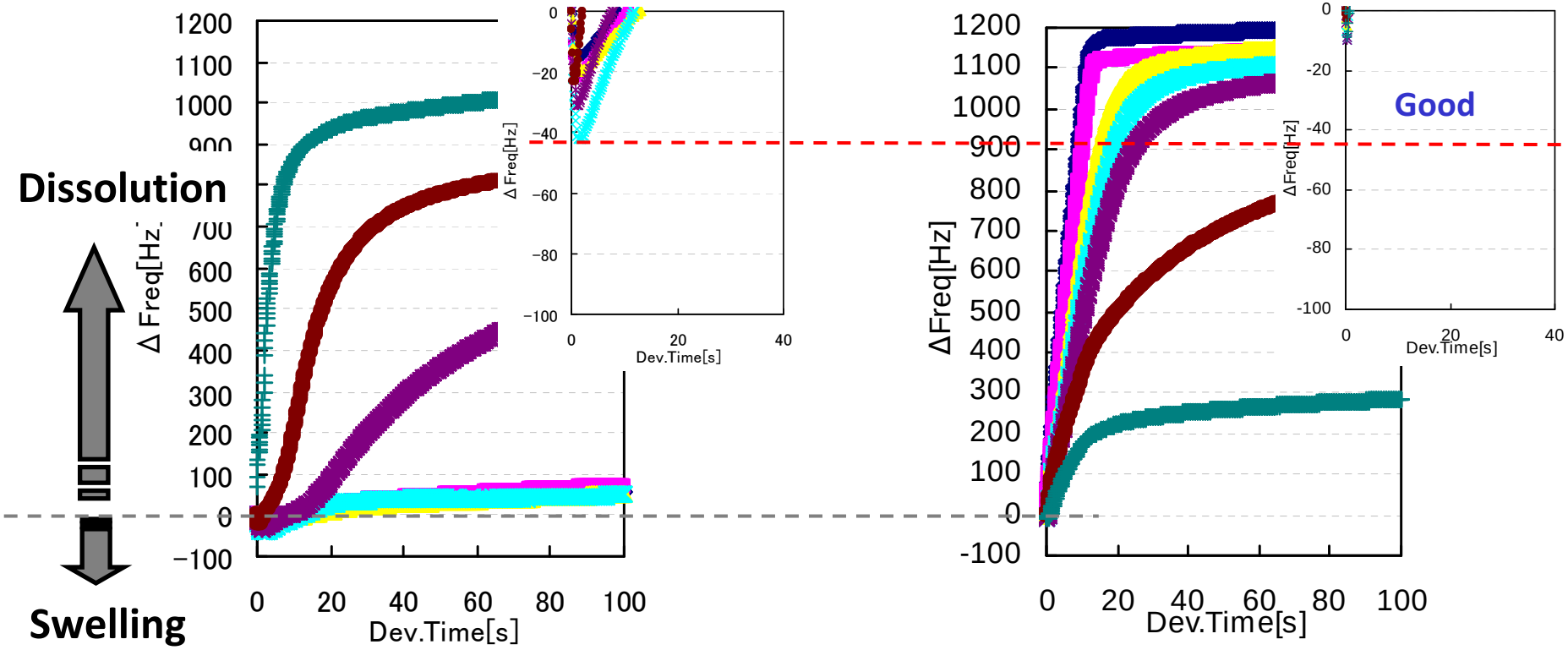
NTI: organic solvent developer
image reversal with polarity switch platform

Swelling comparison by QCM: PTI vs. NTI

QCM Analysis @same resist

PTI developer (2.38%TMAH)

NTI developer (nBA)



NTI demonstrated low swelling character against PTI

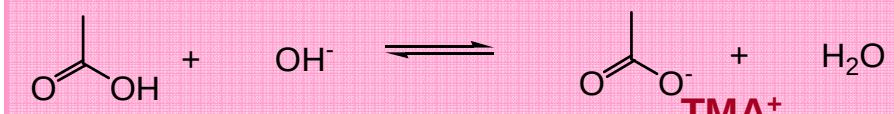
Difference in dissolution mechanism

PTI

Water
+ alkaline

(i) Developer penetration into film

(ii) Acid-base equilibrium reaction



Swelling occurs

(iii) Solvation of polymer

(iv) Diffusion into solvent layer

NTI

Organic solvent (nBA)

(i) Developer penetration into film

No acid-base reaction

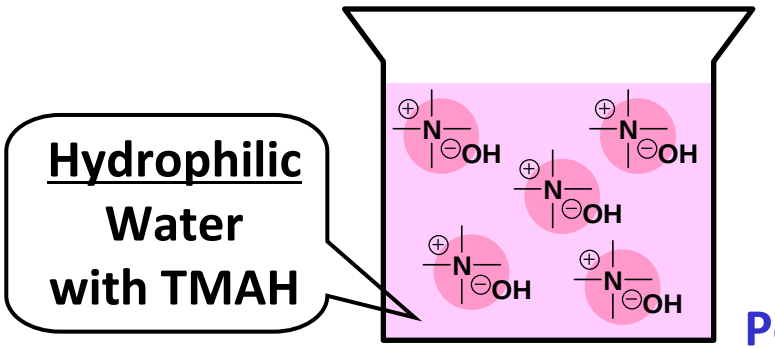
(ii) Solvation of polymer

(iii) Diffusion into solvent layer

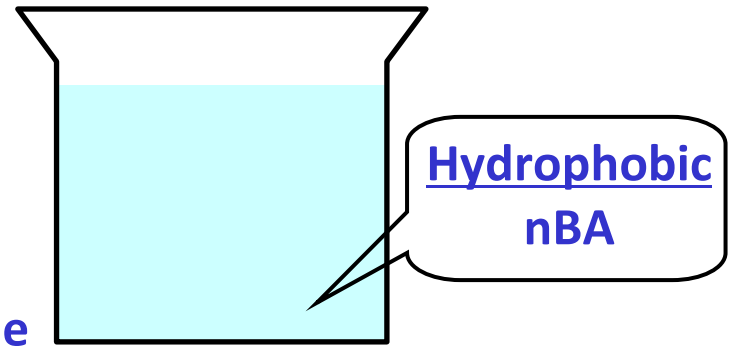
In NTI, once developer penetrates into film, then solvation immediately occurs => no swelling

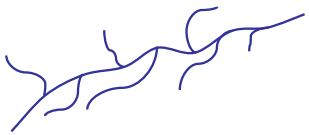
Is NTI ideal for roughness ?

PTI developer

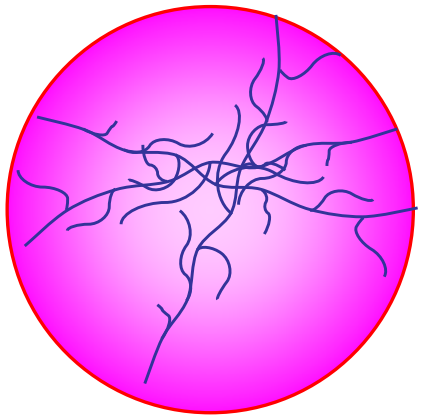


NTI developer



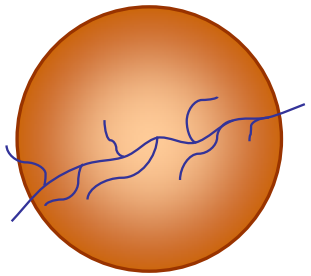


Polymer backbone
= hydrophobic



Aggregation ?

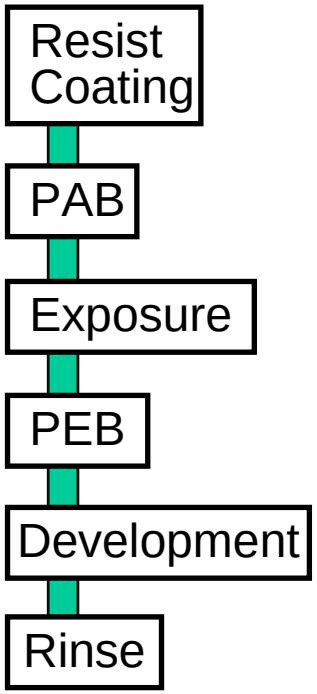
by hydrophobic – hydrophobic interaction ?

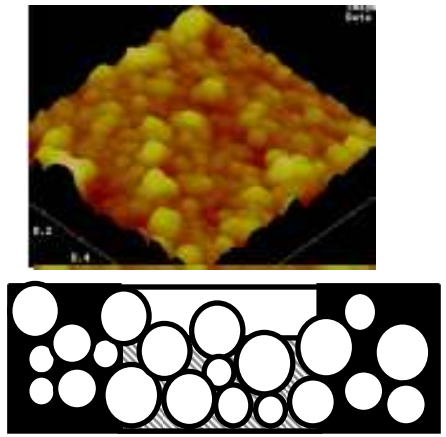


No aggregation ?

Innate roughness: surface roughness study

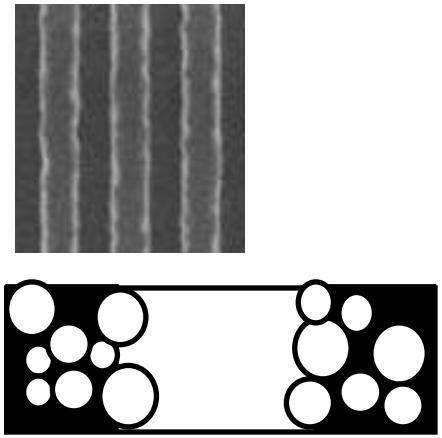
Surface Roughness



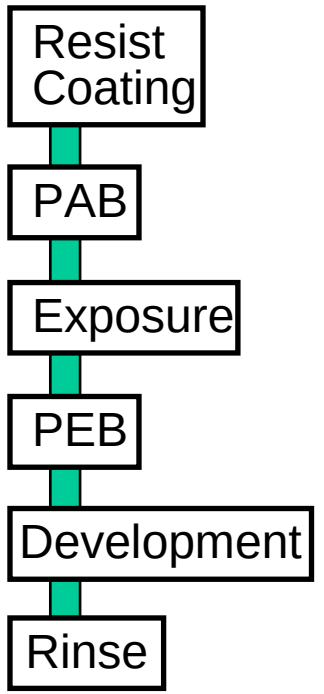


$$Ra = \sum_{i=1}^{n} \frac{z_i - z_{ave}}{n}$$

LWR



$$LWR = 3\sqrt{\sum_{i=1}^{n} \frac{(CD_i - CD_{ave})^2}{n}}$$

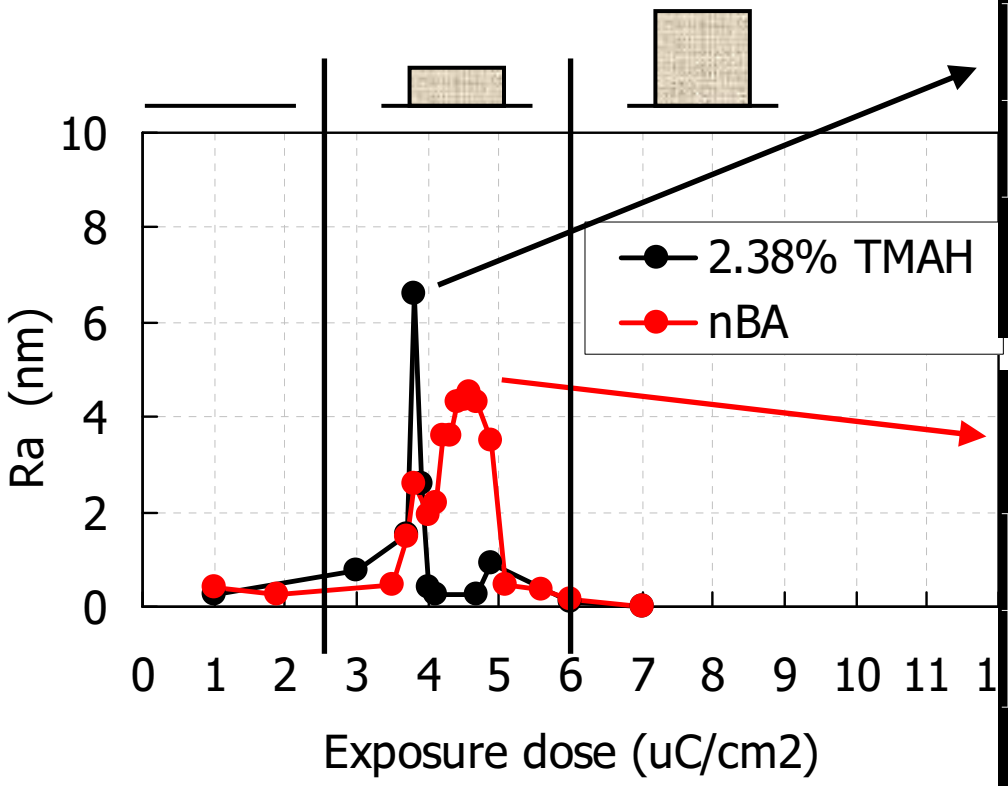


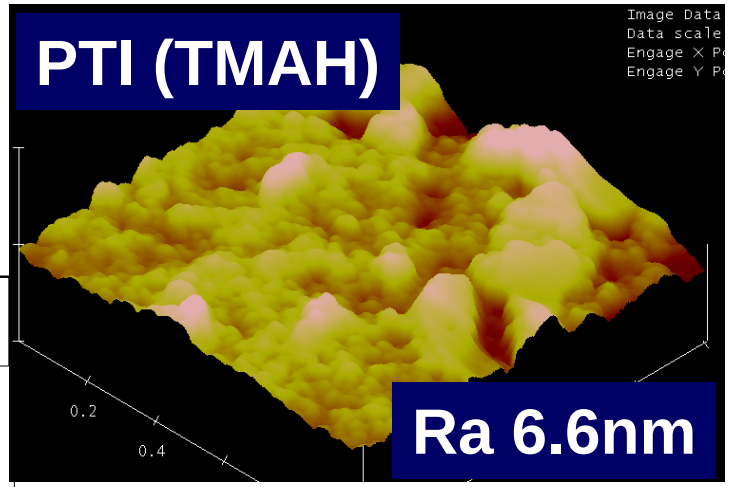
Advantages of surface roughness analysis:

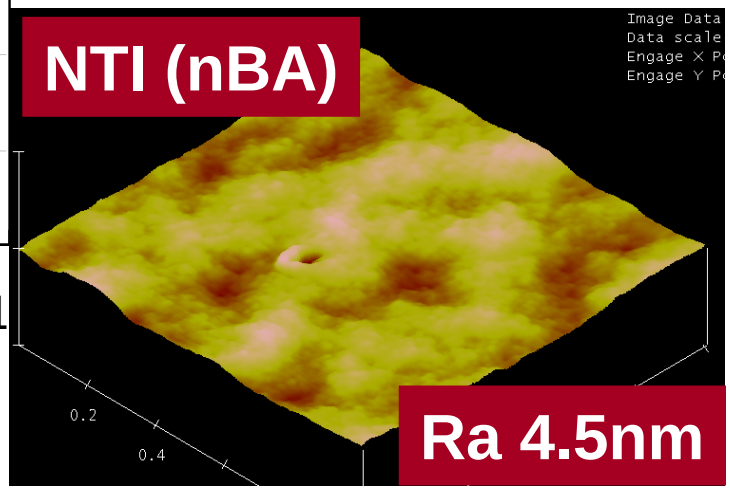
- No optical contrast effect
  - ➔ material's innate roughness can be clarified

Surface roughness comparison

"X-linking type resist"
to avoid any differences before dev.







Film was quite smooth in nBA ➔ small grain !

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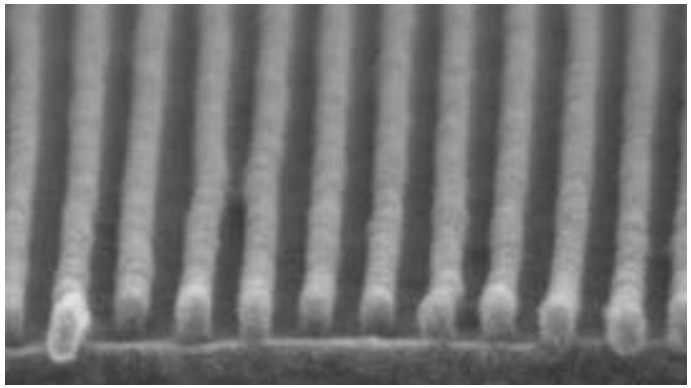
Current best NTI resist

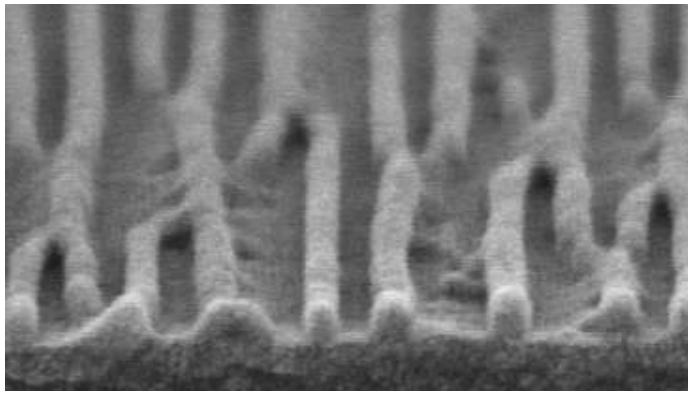
E-beam exposure

NTI @ 40nm FT, 160uC/cm²

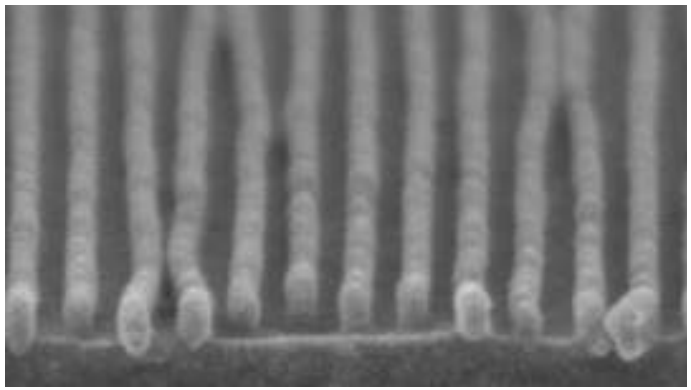
PTI @ 30nm FT, 160uC/cm²

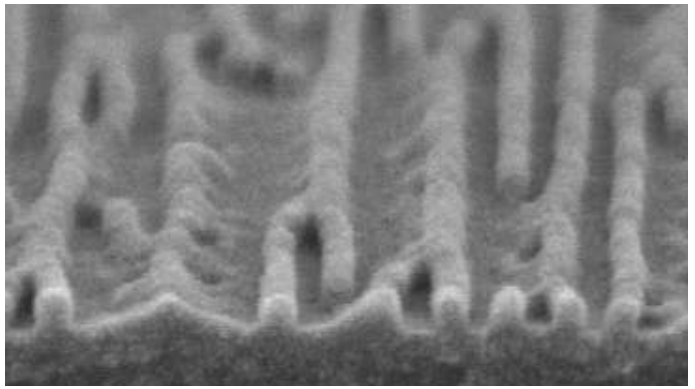
HP 16 nm





15 nm





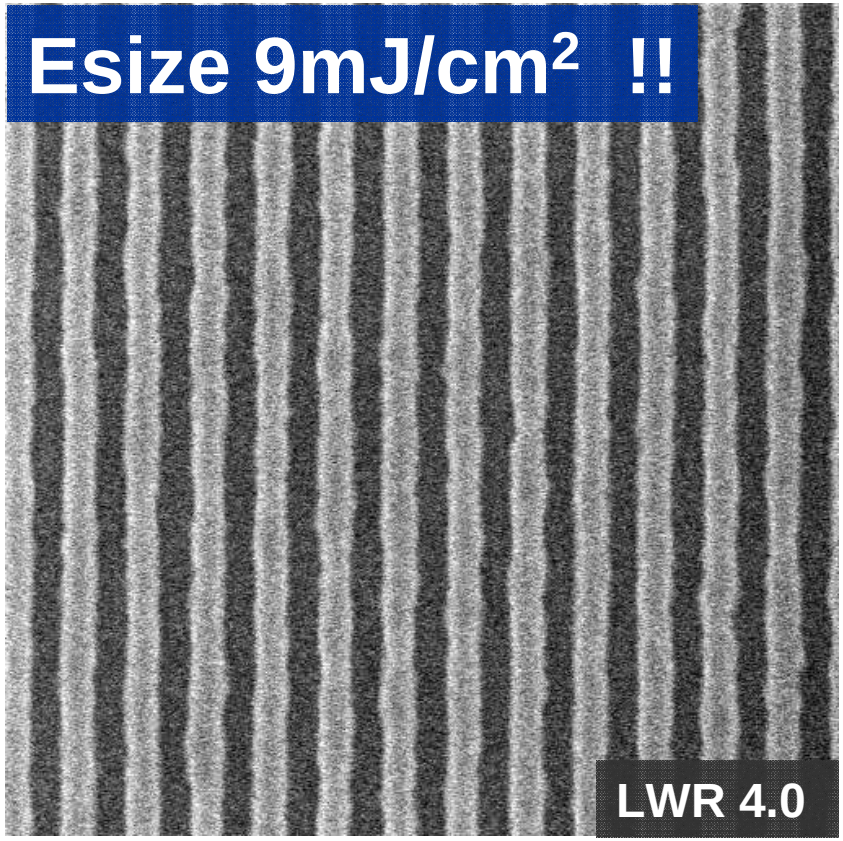
NTI demonstrated 15 nm resolution w. balancing toploss, bridge, collapse

LWR advantage of NTI

26nm hp, EIDEC, NXE:3100 NA 0.25, **Dipole**, 50nm FT

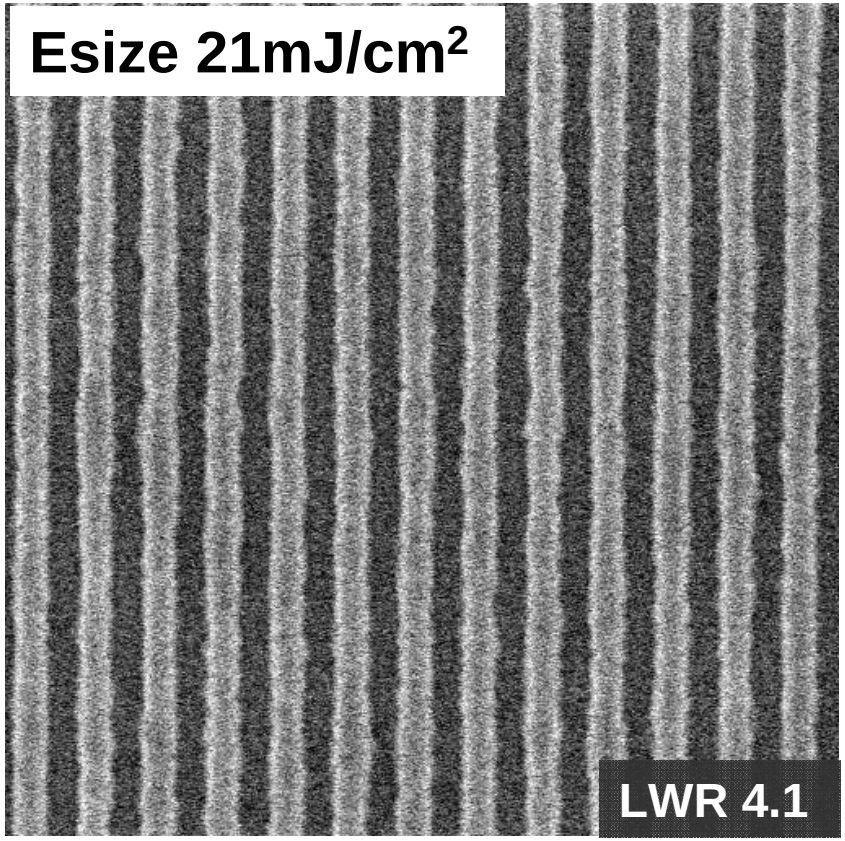
NTI (nBA)

Esize 9mJ/cm² !!



PTI (2.38% TMAH)

Esize 21mJ/cm²



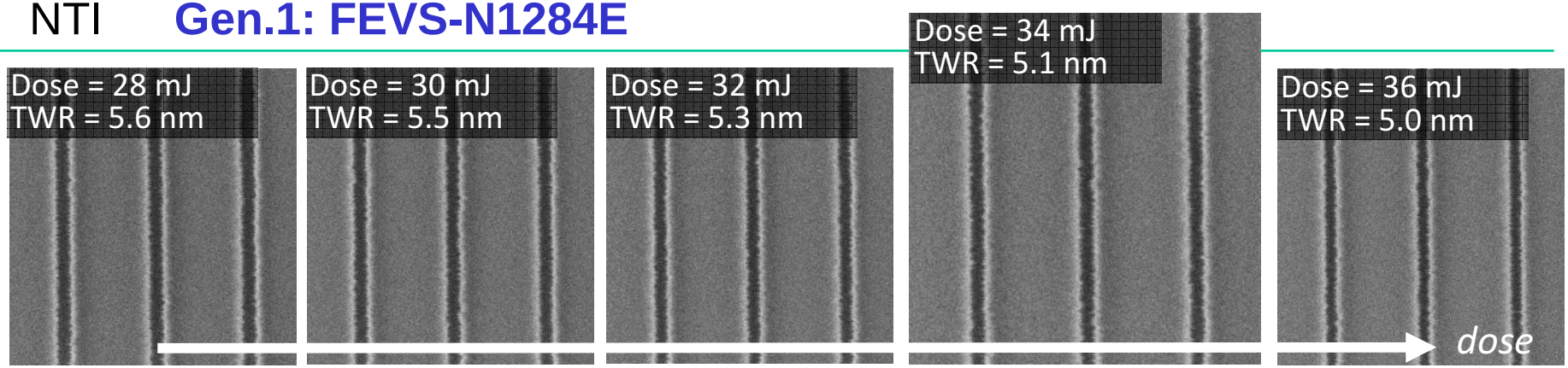
NTI had a demonstrative advantage if pitch is loose

Trench printability

20 nm Trench

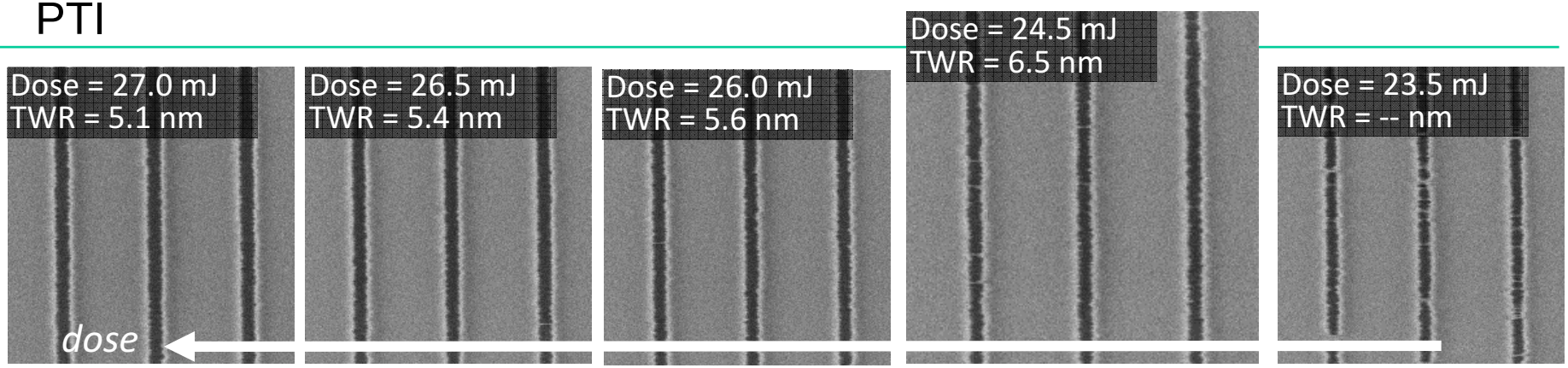
NXE:3100, NA 0.25, Conv. **(σ 0.51)**, 45nm FT

NTI **Gen.1: FEVS-N1284E**



MEAS 23.65 MEAS 22.34 MEAS 21.26 MEAS 20.23 MEAS 18.72

PTI

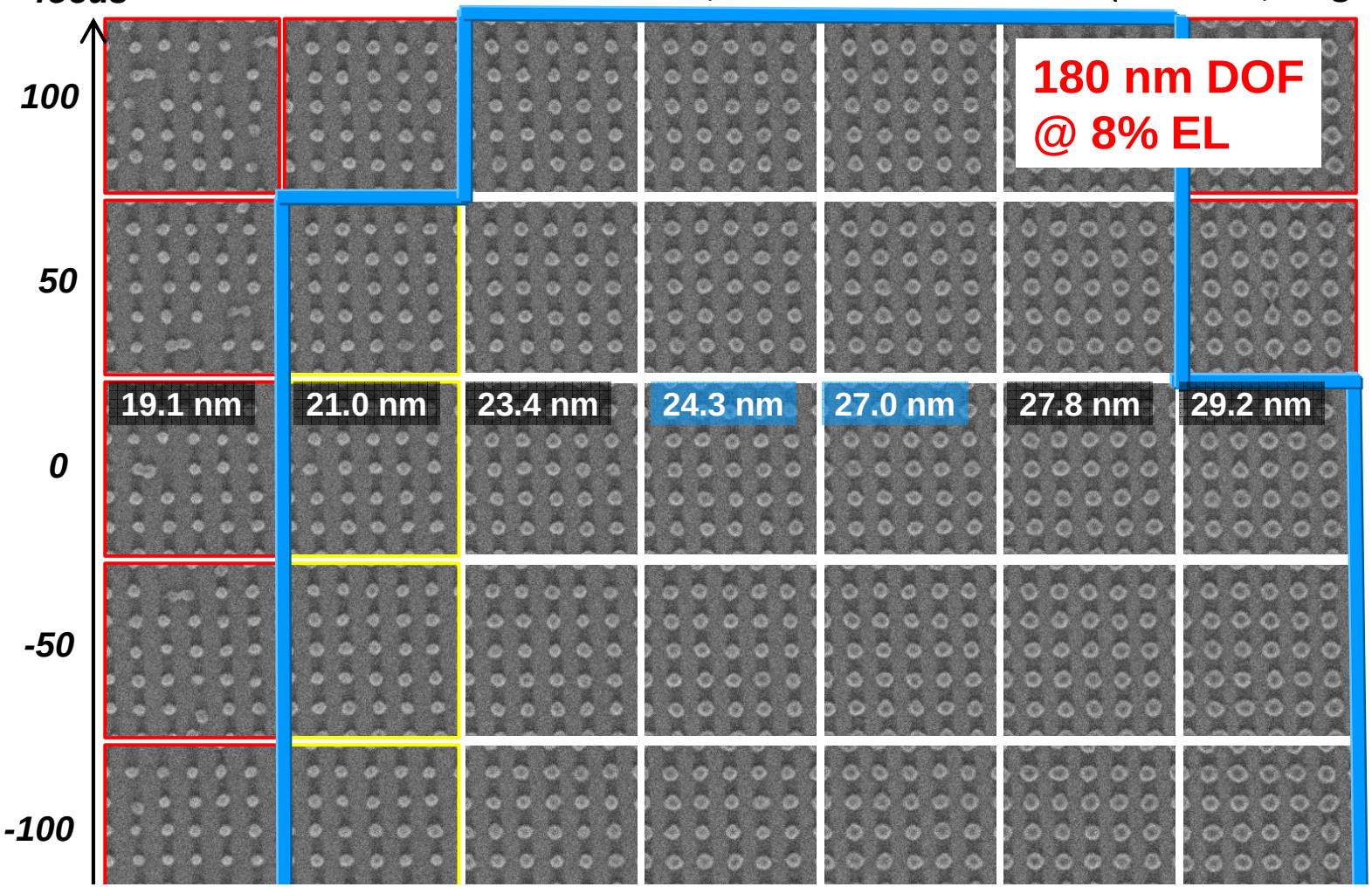


NTI can print narrow trench w./o. bridge

Dot printability

Gen.2 FujiFilm NTI resist

NXE:3100, Dot : 31nmCH 52nmP (on mask, target 26nmDot)



NTI can print 26 nm Dot w./ PW

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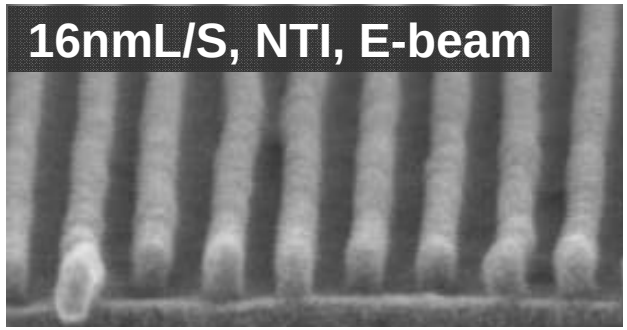
Summary

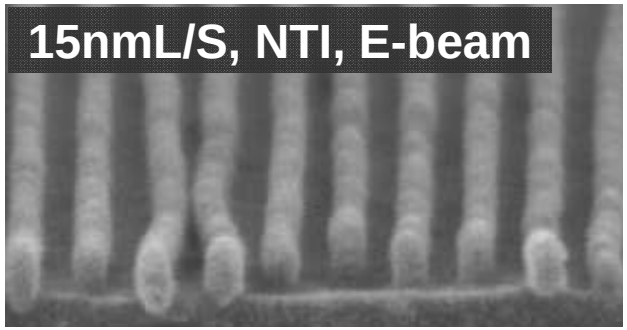
1. **Challenges with PTI process** include toploss, bridge and collapse, all of which limit resolution beyond 16 nm

2. **NTI process with organic developer** address toploss, collapse, bridge and LWR, due in part to less swelling character

3. **15 nm L/S resolution** has been demonstrated using a latest NTI resist, but collapse still limits 14 nm resolution

4. **Better trench and dot (min. 20nm for both) printability** have been confirmed





Acknowledgement

- For the EUV exposure using NXE:3100

imec

- For the EUV exposure using MET

SEMATECH

BERKELEY LAB

Acknowledgement

- For the EUV exposure using NXE:3100.

EIDEC

- For supplying underlayer materials

NISSAN CHEMICAL INDUSTRIES, LTD.

Thank you for your kind attention.

FUJIFILM